*The History of the Multiplex**

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TO BE historically correct the title of this paper should be "The History of the Gasser Projector." In 1917 Dr. Max Gasser, one of the early inventors of photogrammetric instruments and procedures built the first "double projector." This incorporated practically all basic design elements which today are found in the successors to this pioneer instrument. I chose "Multiplex" as the title of this paper since this trade name is so well established in the minds of photogrammetrists throughout the world that it immediately sets up a familiar background to the story of mapmaking from aerial photographs.

The veteran instrument, the Gasser projector (Figure 1), still may be inspected in the German Museum at Munich, Germany. It was conceived as a stationary instrument suspended from an overhead I-beam. It projected normal-angle photographs on glass plates of 13×18 cm. format onto a mapping table placed beneath the I-beam at approximately 1,500 mm. projection distance. The projectors had a principal-distance of 21 cm. Some 30 years later this instrument was succeeded in Europe and the United States by a number of similar designs. These will be reviewed briefly in this paper.

The idea of a multiple-projection plotter of portable size must be credited to Dr. W. Bauersfeld. At the Carl Zeiss Works of Jena, Germany, he produced, in 1931, the first prototype of a three-protoytpe instrument. He named it Aeroprojector Multiplex. It was then a small desk-supported appratus. A short horizontal bar in the form of a T-square, standing on three tubular legs of adjustable length, furnished the guide rail along which the projectors were aligned. The projectors held diapositive transparencies of 46×54 mm. These were produced in a reduction printer of utmost simplicity and which had a fixed ratio of approximately 1:4.5. The condenser housing above the diapositive stage had a 6 volt 50 watt incandescent lamp and gave full field satisfactory illumination at an optimum projection distance of 270 mm. The angular coverage was 65°.

This instrument made its first appearance in the United States in 1934. Its great potentiality was immediately envisioned by General Douglas C. MacArthur, then Chief of the U. S. Engineers. It was soon adopted by the Corps of Engineers as the future field equipment for survey battalions and was standardized with the Armed Forces after a domestic source of supply had been established at Rochester, N. Y.

The U. S. Geological Survey for a long time had been using photogrammetric procedure in its mapping operations. It recognized the economic advantages offered by this new instrument which particularly emphasized the possibility of aligning a larger series of projectors on an extended supporting bar. As a result, the number of ground control points normally required for each individual stereomodel could be materially reduced.

The Tennessee Valley Authority, which was charged with the gigantic task of rapidly mapping 40,000 square miles of the Tennessee River watershed at a scale of 1:24,000,

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reorganized its entire field force in 1936. It based its operation on the use of the Multiplex instrument which by that time had been equipped with wide-angle projectors with an angular field coverage of 90°.

Under the direction of T. P. Pendleton, R. K. Bean began an elaborate development program of adapting the new instrumentation to the requirements of aerial photography in the United States and to U. S. Geological Survey mapping standards. The wide scope of creative work, problems to be solved, and changes to be introduced in rapid sequence, under the pressure of tight production schedules in Chattanooga, Tennessee, and in Rochester, New York by Bausch & Lomb, can be appreciated only if remembered that the original Multiplex concept had been solely aimed at the production of topographic maps of small scales. These were hardly in excess of 1:50,000 and featured contour intervals of 25 to 50 meters which do not approach the high standard of accuracy considered obligatory in our days. Also the original system did not take into consideration the compensation of radial distortion of the aerial camera lens, the variations of its focal-length due to manufacturing tolerances, the shrinkage of the film base, and rigid uniformity of the principal-distance of the projectors. As a result the deformation of stereo-models from the datum plane varied from 0.5 to 1.0 millimeters.

In 1939 Dr. K. Pestrekov and his associates in Rochester thoroughly analyzed error sources of optical and mechanical origin and established a new set of specifications for the entire projection system. An essentially different wide-angle projector of 30-millimeter principal-distance was created (Figure 2). This employed diapositive transparencies of 64×64 mm. format, an improved projection lens of 93° field-angle, and a highly corrected refractive condenser system capable of furnishing full field illumination at a high intensity level from a 20-volt, 100-watt incandescent lamp. A more complex printer with variable reduction ratio, capable of correcting camera focal-length and film-shrinkage variations, and producing diapositives of better image rendition, was designed. The model flatness of the

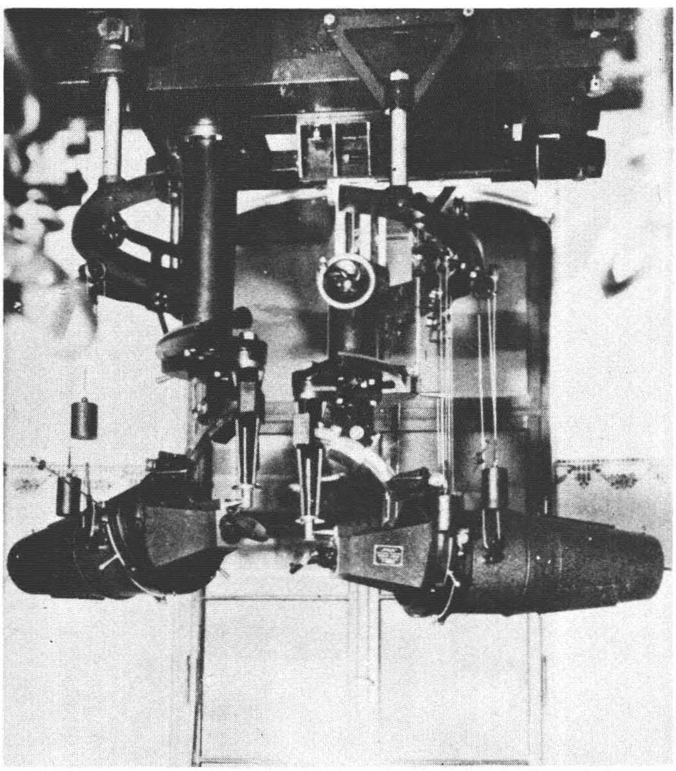

FIG. 1. The Gasser Projector, built in 1917, was the first double projection plotter for topographic mapping. Its normal angle projectors were suspended from an I-beam. The projector axes were arranged horizontally. 45° mirrors bent the paths of projecting light rays vertically downward. Each projector was rotatable about the three axes of a rectangular coordinate system and translatable along the x and z axes.

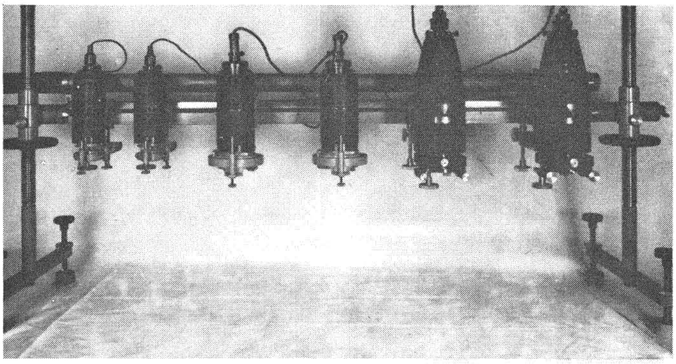

FIG. 2. The first Multiplex projectors, built by Carl Zeiss, Jena in 1932 were normal angle projectors for 46×54 mm. diapositives. Wide angle projectors, also built by Zeiss came into use in 1936. Further development at Bausch and Lomb since 1938 produced precision projectors of 64×64 mm. diapositives size and larger physical dimensions but retained refractive condenser illumination systems.

entire system was specified as 0.15 mm. This was soon exceeded in practice.

Multiplex mapping operation assumed enormous proportions, due to acceleration by military necessities on world-wide theaters of operation and to the tremendous civil pressure for mapping in the post-war period. This brought about a continuous refinement of Multiplex components responsive to new applications, for instance, special projectors for convergent, high-oblique and tri-metrogon photography. These projectors were equipped with tilted projection lenses designed to tilt the plane of best focus into the mapping plane.

Until 1948, however, extension of control utilizing the bridging ability of the Multiplex, had met with only moderate success. This was due to excessive radial distortion of the diapositive plates which the reduction printer left uncorrected. The first step toward rigid control of this distortion problem was taken by J. V. Sharp. He introduced a modulated diapositive plate which was produced by a rapid automatic grinding process. Although successful in principle it was soon superseded by newly developed equipment and techniques to produce large-size aspheric corrector plates. These became optical components of th re-duction printers. Since then it has been possible to control residual radial-distortion throughout the system to within 10 microns.

In 1947, Harry Kelsh published the first results of an experimental projection apparatus which was intended for large-scale mapping from diapositives equal in size to the aerial negatives. Full field illumination was attempted but this offered difficulties similar to those that Gasser experienced in 1917. Kelsh consequently changed over to partial field illumination by using a mobile light source of the form that Gallus-Ferber of France had applied to his "L'aero System" instrument of 1931. He furthermore added an ingenious feature for the mechanical correction of radial distortion, the spherical cam at the head of the guide rod linking the illuminator with the tracing table—a solution which Santoni of Italy had introduced in 1929 in his Stereoautograph plotting machine. A detailed report on this development was given a year ago by Mr. R. H. Smith in a paper entitled "The Story of the Kelsh Plotter." A reading of this paper is suggested.

For completeness of the historical record it should be added that Bausch & Lomb built a prototype Kelsh plotter as a contribution to the International Congress of Photogrammetry in 1952. This plotter offered the correct solution of light source and spherical cam guidance; this since then has been adopted by other plotters of this type.

There are now on the market several successors to the Kelsh instrument. They display the same principle of the solution but feature variations in the design components. The British version which is called the Williamson Large Scale Plotter uses alternating projection of the images superimposed on the tracing table, by means of gas discharge lamps. An elegant solution of the cumbersome guide-rod principle is offered in the Photomapper by Nistri, Italy. There, the guided projection lamps are linked together by a simple adjustable cross-slide system which is moved by a single guide-rod attached behind the tracing table. Correction of radial-distortion is provided by aspheric corrector-plates built into the projectors.

An extreme solution to mapping from high-altitude convergent-photography has been attempted by ERDL, Fort Belvoir, with the

Halcon Plotter built by Fairchild, Los Angles. Although specific data are not available, it is known that the nominal magnifications of the negative scale are 5× and 10× and the resultant necessity of super-extensible guide-rods becomes a real calamity, as can be readily envisioned.

This guide-rod nuisance can be completely dispensed with if the mobile illuminators follow the movement of the tracing table by electronic guidance. The Bausch & Lomb solution uses a guidance system which links sensors located at the centers of perspective to the tracing platen, by invisible rays of light. The projector again fits the conventional Bausch & Lomb supporting bar and has a universally tiltable lens which permits the rectification of the projector depth zone in any desired azimuthal direction. It is designed for 5× magnification of the aerial negative scale.

A decisive step toward expanding the mapping range of the Multiplex system into the regions of engineering and cadastral map-scales was undertaken by the U. S. Geological Survey in 1951. This involved the design of a projector having slightly increased physical dimensions and included the development of a new illuminating condenser, which provides the highly desired full field illumination at an intensity level exceeding that of conventional refractive condensing systems. This new equipment, initiated by R. K. Bean and produced by Bausch & Lomb in Rochester, is known as the ER-55 or, in the commercial version, the Balplex Projector. Its design parameters are based on the following:

1) The present Multiplex reduction ratio of 1:4.5 used in preparing the diapositive working plates, and the subsequent magnification during the mapping process, aggravates the problem of identification of map-worthy detail on the model surface.
2) The present short projection distance of 360 mm. makes impracticable drawing the manuscript at a scale consistent with sound surveying practice.
3) The advanced state of the art of producing higher-resolution optics and higher-resolution photographic emulsions permits a two-to-three-times reduction in the transfer process from negative to diapositive, without detriment to accuracy and completeness of the final map product. The retention of the original negative scale on the diapositive plate is, therefore, unnecessary.

The ER-55 Balplex wide-angle projectors of 90° field-angle use 110×110 mm. diapositive-plates, a principal-distance of 55 mm., and distortion-free lenses tiltably mounted to achieve rectification of the depth zone in mapping obliques (Figure 3). They are presently available with nominal projection distances of 525 mm. (3.5×magnification for medium-scale mapping) and 760 mm. (5×magnification for large-scale mapping). A third projector will be available in the near future for small-scale mapping at 400 mm. nominal projection-distance. The ellipsoidal reflectors render illumination levels in excess of 12 foot-candles in the corners of the field when projected at 525 mm. distance. Model flatness is corrected to ±75 microns deviation from the plane. The projectors weigh less than wide-angle Multiplex projectors; they can be mounted on the conventional Multiplex bars without alteration.

A special version of the ER-55 has been built for the USGS Twinplex instrument which serves exclusively for mapping from 20° twin convergent and transverse oblique photography. A modified plotting technique is used in the Gamble Plotter built in Canada; this provides a fixed mapping platen and an elevating mechanism for the projector bar.

Before closing this historical account it may be well to add a few words concerning future expectations.

Super-wide-angle aerial photography has come into being since 1959; it cannot be denied that the step from 90° to 120° is as significant and far reaching as was in 1934, the step from 65° to 90° field-angle. The base/height ratio as a governing factor of the geometrical rigidity of the photogrammetric restitution was increased from 0.36 to 0.60 in 1934; this brought an improvement of vertical measuring capability by a factor of approximately two. The base/height ratio at 60% overlap of consecutive 120° photographs stands at 1.00. The renewed increase of strength of the intersecting rays forming the surface of the 120° stereo-model holds promise of again improving the vertical measuring acuity by a similar factor. Besides, the photographic coverage of a 120° photograph under otherwise identical conditions is increased by a factor of three. The economic consequences are inevitable, although there are limitations to the usefulness of 120° photography. Primarily the new type of aerial photography will advantageously be used for topographic mapping at medium and small scales and of terrain of medium and low relief.

To exploit the new economic prospects in a most economic way a new member of the

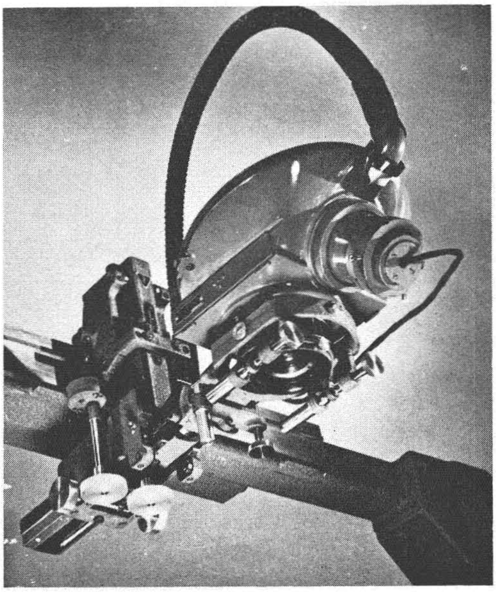

FIG. 3. The ER-55 Balplex projectors present the newest state of the Multiplex developments with a greatly increased range of application and accuracy. Diapositive plates are of 110×110 mm. format. Vertical, oblique and convergent photography up to 60° tilt can be plotted within the depth zone of the projection lens rectified by canting of the lens. An ellopsoidal reflective condenser system provides uniform illumination at nominal projection distances of 525 and 760 mm. suitable for medium and large scale mapping. Another type is equipped with a projection lens of 120° angular field using super-wide-angle photography for small scale topographic mapping, also from 110×110 mm. diapositive plates.

family of Multiplex projectors has made its appearance. It is named the 120° Balplex projector. It once more shows the familiar shape of 90° projectors with slightly increased physical dimensions. The size of its diapositive format is unchanged since it is printed in the same printer serving the 90° projector. The nominal projection distance is approximately 400 mm. resulting in about 5× magnification of the negative. The lens is distortion-free, resolves better than 100 lines/mm. on axis and 28 lines/mm. at 60° off axis. It is tiltably mounted to take care of any conceivable combination of vertical, oblique and/or convergent photography. A new record has been set of the level of illumination on the mapping table resulting from several sources of refinement, especially from a new ellipsoidal reflector, a direct replication from a master of increased dimensions. For its perfection a new concept of automatic generator was put into operation; this carries out the entire action from rough grinding to fine polishing in one single unique setup. Exhaustive tests of model flatness showed deviations from the datum plane of 0.15 mm. within the gross area, and 0.10 mm. in the neat area of the grid model. Again the use of this new projector requires no change in the existing support equipment, power supply, centering device, and tracing table.

In closing let me say that there is no end in sight for further advancements in the design and performance of multi-projection instrumentation. The steady progress anticipated in optical design and in the electric and electronic fields point toward a day in the near future when the operator will prefer a lower level of illumination than the projector is capable of supplying. Only a few years ago a former authority in these matters ventured to brand the category of projectors reviewed here as "dull-sighted" instruments. In view of their unparalleled record of performance this category appears to be more "bright-sighted" than ever before.

Announcement

PHOTOGRAMMETRIC ENGINEERING

Important Changes Coming

Those who have been confused by the 5 issues-per-year basis will be highly pleased to learn that the Board of Direction has approved changing to 6 issues per year, that is bi-monthly.

The change will not be fully effective until 1963 with the January issue being numbered 1. In 1962 there will be 5 issues as now. The months of issue will be March, May (formerly April), July (formerly June), September and November (formerly December). For advertising, there will be no change in base rates, frequency reduction, agency commission and also the 2% if earned. Beginning with the second issue in 1962, the closing dates will be changed.